PATENT SPECIFICATION

(11) 1 525 745

1 525 745

(21) Application No. 38415/75 (22) Filed 18 Sept. 1975
(31) Convention Application No. 49/108531
(32) Filed 19 Sept. 1974
(31) Convention Application No. 49/108533
(32) Filed 19 Sept. 1974
(31) Convention Application No. 49/108532
(32) Filed 19 Sept. 1974
(31) Convention Application No. 49/108528
(32) Filed 19 Sept. 1974
(31) Convention Application No. 49/108530
(32) Filed 19 Sept. 1974
(31) Convention Application No. 49/108529
(32) Filed 19 Sept. 1974
(31) Convention Application No. 49/109098
(32) Filed 20 Sept. 1974
(31) Convention Application No. 50/006565
(32) Filed 14 Jan. 1975
(31) Convention Application No. 50/047030
(32) Filed 17 April 1975 in
(33) Japan (JP)
(44) Complete Specification published 20 Sept. 1978
(51) INT CL² H01F 5/00
(52) Index at acceptance
H1T 15 1F 7C3 9

(19)

(72) Inventors MASATAKE AKAO
YOSHIKAZU YOKOSE
KAZUO YAMASHITA and
TAKASHI SHIBANO

(54) SYNTHETIC RESIN ENCAPSULATED COIL ASSEMBLY

(71) We, MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD., a Japanese Body Corporate, of 1006 Oaza Kadoma, Kadoma-shi, Osaka, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to a synthetic resin encapsulated coil assembly for use in an electric circuit.

As shown in Figs. 1 and 2 of the accompanying drawings which are respectively a perspective view of a prior art syntheric resin encapsulated coil assembly and a cross sectional view thereof taken along the line II—II in Fig. 1, a known form of coil assembly comprises a wound coil 1 having a plurality of turns 2 of insulated wire, made of electric conductive material such as copper, iron or aluminum, of which the opposite ends form leads 4 for external electric connection, the wire turns 2 representing, as best shown in Fig. 2, a bundled configuration in section. The assembly of wire turns 2 of the coil 1 is externally covered with an electrically insulating layer of synthetic resin 3 by means of an injection moulding technique or a plastics die casting technique.

However, it has been found that, during the use of such a known coil assembly in an external electric circuit, internal stress builds up in the resin layer 3 due to the difference in thermal expansion coefficient between the synthetic resin for the layer 3 and the material for the wire of the wound coil 1 and, therefore, in most cases, the internal stress build-up results in the formation of cracks in the resin layer 3 leading to a substantial malfunction of the coil assembly or otherwise insufficient performance of the same.

This drawback may be removed by using, for the layer 3, a synthetic resin containing a relatively large amount of inorganic powdery filler which is added thereto in

order for the thermal expansion coefficient of the resin layer 3 to equal, or at least approximate to that of the electric wire of the wound coil 1. Although this may result in relief of the internal stresses, the physical strength of the layer 3 is adversely affected to such an extent that the resultant coil assembly can no longer withstand relatively high electric loads. Moreover, the use of the synthetic resin containing inorganic powdery filler for the layer 3 does not completely avoid the possibility of the formation of cracks in the layer 3 and, therefore, the resultant coil assembly is liable to a substantial malfunction or, at any rate, reduction in performance.

During manufacture, the addition of the inorganic powdery filler to the synthetic resin for the layer 3 causes an increase of the viscosity of the synthetic resin in its molten state and, therefore, the impregnation and injection-moulding process require a relatively long time. Moreover, during the impregnation stage, voids tend to develop and the resultant layer 3 will not exhibit a desired or required electric property.

In general, the respective thermal expansion coefficients of the electric wire for the coil 1 and the synthetic resin for the layer 3 may be substantially equal to each other if the temperature evolved in the coil assembly during the use in an external electric circuit is lower than the heat distortion temperature of the synthetic resin for the layer 3, that is, the temperature at which heat distortion takes place in the layer 3. However, where the temperature evolved in the coil assembly is higher than the heat distortion temperature, the thermal expansion coefficient of the synthetic resin for the layer 3 increases but the thermal expansion coefficient of the electric wire for the coil 1 remains substantially the same. Therefore, the difference in thermal expansion coefficient results in a considerable stress build-up in the layer 3. Hence the prior art coil assembly lacks a sufficient resistance to cracking with a consequent reduction in temperature resistance.

According to the present invention, there is provided a synthetic resin encapsulated coil assembly which comprises a wound coil consisting of a plurality of turns of insulated wire bundled together, a covering of synthetic resin containing a high strength fibrous material, said covering surrounding the bundled turns of insulated wire of the wound coil, an intermediate insulating layer positioned between the coil and the covering, and a semi-conductive layer positioned between the intermediate insulating layer and the covering.

Reference will hereinafter be made to the accompanying drawings, which illustrate, by way of example, various preferred embodiments of the present invention, and in which:

Fig. 1 is a perspective view of the prior art coil assembly;

Fig. 2 is a cross sectional view, on an enlarged scale, taken along the line II—II in Fig. 1, reference to Figs. 1 and 2 having already been made in the foregoing description;

Figs. 3 to 5 illustrate diagrammatically various methods of winding a thread or roving of high strength fibrous material around a wound coil of turns of electrical insulated wire, wherein Fig. 3 is a similar view to Fig. 1 showing the thread or roving of high strength fibrous material being wound to form substantially parallel turns thereof, Fig. 4 is a perspective view of a portion of the coil assembly showing the thread or roving of high strength fibrous material being wound to form substantially cross turns and Fig. 5 is a view similar to Fig. 4 showing a tape of high strength fibrous material being wound to form substantially overlapping turns;

Figs. 6 and 7 illustrate different methods of applying to the outside of a wound coil a covering of synthetic resin containing a high strength fibrous material; and

Figs. 8, 9 and 10 illustrate cross sectional representations of three different embodiments of a coil assembly according to the present invention.

Before the description of the present invention proceeds, it should be noted that like parts are designated by like reference numerals throughout the accompanying drawings.

Referring first to Figs. 3 to 5, a wound coil 5 having a plurality of turns of insulated wire is surrounded by a covering 6 containing high strength fibrous material, (as hereinbefore defined) such as glass fibres or glass rovings which is wound around the coil 5 as shown.

The high strength fibrous material may be toroidally wound around the bundled turns 2 of the wound coil 5 to form substantially parallel turns such as shown in Fig. 3, or may be wound around the bundled turns 2 of the wound coil 5 to form substantially crossing turns such as shown in Fig. 4. The high strength fibrous material may be employed in the form of a continuous tape, which may be wound around the bundled turns of the wound coil 5 to form substantially overlapping turns such as shown in Fig. 5. In practice, a combination of the methods of Figs. 3 and 4, or of Figs. 3 and 5, or of Figs. 4 and 5, or of all of Figs. 3 to 5 can be employed. Additional turns of the high strength fibrous material 6 may extend in parallel

relation to the direction of turns of the electric wire forming the wound coil 5. Other methods of covering the coil 5 with the high strength fibrous material 6 other than those shown in any of Figs. 3 to 5 may be selected if desired.

If it is not considered suitable for the high strength fibrous material 6 to be wound around the coil, for any reason, the fibrous material may be arranged around the outermost bundled turns 2 of the wire forming the wound coil 5 in any other suitable manner resulting in the entanglement of the fibres of the material 6. This alternative is unlikely to be detrimental to the performance of the finished coil assembly according to the present invention.

The high strength fibrous material 6 may be selected from the group consisting of glass, carbon, boron, silica, alumina and "Kevlar" (Trade Name used by Du Pont). The high strength fibrous material 6 may be in the form of threads or rovings, as shown diagrammatically in Figs. 3 and 4, a tape, as shown in Fig. 5, a cloth, a non-woven cloth, a mat or any other suitable form.

The wound coil 5 formed by the bundled turns 2 around which the high strength fibrous material 6 is to be wound is first impregnated with synthetic resin under substantially vacuum atmosphere so as to allow the synthetic resin to penetrate into interstices among the bundled turns 2 of the wire. Once the impregnated synthetic resin has hardened, the electrically insulating layer constituted by the high strength fibrous material 6 which is uniformly enveloped and thus reinforces additional synthetic resin, is formed around the outermost bundles, turns 2 of the wire forming the wound coil 5, this additional synthetic resin preferably having no voids therein.

Two methods of providing the electrically insulating layer of fibrous material reinfored synthetic resin are illustrated in Figs. 6 and 7, respectively, in which unhardened synthetic resin is applied to the high strength fibrous material before it is wound around the outermost bundled turns of the wire of the wound coil 5, the synthetic resin applied to the high strength fibrous material being subsequently allowed to harden. It will readily be seen that, because of the presence of the high strength fibrous material, the synthetic resin applied thereto once hardened is reinforced thereby to provide the insulating layer. The synthetic resin used in either of the methods illustrated in Figs. 6 and 7 may, if desired, contain a filler material.

Referring now to Fig. 6, before the high strength fibrous material 6 is wound around the bundled turns of insulating wire forming the coil 5, the high strength fibrous material 6 is passed through, i.e. continuously immersed in, a solution 13 of the synthetic resin which is accommodated in a container 12 so as to apply the synthetic resin 13 to the high strength fibrous material 6. As the high strength fibrous material 6 is wound around the bundled turns of insulated wire forming the wound coil 5, the high strength fibrous material 6 is held under a predetermined tension to allow excessive synthetic resin or any voids in the synthetic resin 13 to be removed.

In the method shown in Fig. 7, before the high strength fibrous material 6 is wound around the bundled turns of wire of the wound coil 5, the high strength fibrous material 6 is fed between a pair of juxtaposed rollers 14. One of the juxtaposed rollers 14 which is rotatably supported above the other roller is positioned below a nozzle at the bottom of a container 12 for a solution 13 of synthetic resin so that the latter can be supplied onto the upper roller 14 through the nozzle 16. It will readily be understood that, in this way, the solution 13 of synthetic resin is applied to the high strength fibrous material 6 through the rollers 14. By adequately adjusting the clamping force exerted by the juxtaposed rollers 14 on the high strength fibrous material 6 passing therebetween, the high strength fibrous material 6 can be moved under a predetermined tension and subsequently wound around the bundled turns of wire of the wound coil 5 to form the high density electrically insulating layer of reinforced synthetic resin. In a substantially similar manner to the method of Fig. 6, because of the tension imparted on the high strength fibrous material 6 during the winding operation, excessive resin, and/or voids contained in the synthetic resin applied to the high strength fibrous material 6, can advantageously be removed.

However, complete removal of any voids which may otherwise be left in the insulating layer would be difficult without proper control of, for example, the tension of the high strength fibrous material 6. In such a case it is recommended to carry out the winding operation of the high strength fibrous material 6 to which the synthetic resin has already been applied, under a substantially vacuum atmosphere to ensure a complete removal of the voids.

Other methods of applying synthetic resin to the high strength fibrous material and winding the resultant layer onto the coil 5 may be contemplated. For example, the synthetic resin may be applied to the high strength fibrous material by heatfusing technique, the synthetic resin being such that it is solid under ambient temperature

and can therefore be applied when in a molten state and subsequently allowed to harden after the high strength fibrous material with the synthetic resin applied thereto has been wound around the bundled turns of wire of the wound coil 5. Alternatively, the synthetic resin may be mixed with a hardening agent before being applied to the high strength fibrous material 6, the resin being subsequently semi-cured to harden it at least partially.

It is also possible for the layer of fibre reinforced synthetic resin to be applied to the coil 5 in a plurality of plies.

According to either of the methods described with reference to Figs. 6 and 7, the operation of winding the insulating layer of synthetic resin reinforced by the high strength fibrous material results in the fibres being entangled and effectively uniformly distributed around the bundled turns of wire of the wound coil 5.

If the insulating layer is wound around the coil 5 directly over the bundled wires thereof, it is possible that incomplete bonding may occur between the insulating layer and the wires and/or the synthetic resin already provided in the interstices between the wires, and this is particularly so when the cross sectional shape of the coil 5 is rectangular or square, where the fibres in the resulting layer may be inadequately bent around the corners of the coil 5, leaving only synthetic resin adjacent the wires in the coil 7.

If the wires in the coil 5 are aluminum or copper, the thermal expansion coefficient thereof is respectively about 2.2×10^{-5} or 1.6×10^{-5} cm/cm/°C., and if the synthetic resin used is epoxy resin, its thermal expansion coefficient is 5×10^{-5} cm/cm/°C at room temperature and 4×10^{-4} cm/cm/°C at 150 to 200°C. Accordingly, if only synthetic resin is adjacent the wires in the coil 5, considerable stresses will be set up in the resin as the temperature increases during the use of the coil assembly, probably causing the formation of cracks. Once cracks occur in the resin around the wires, corona discharge occurs at those portions of the resin where the cracks are formed upon application of a relatively high voltage to the coil assembly and, therefore, the durability of the coil assembly is reduced.

The solution to this problem, illustrated in the embodiments of the invention shown in Figs. 8 and 9, is the inclusion between the insulating layer 8 of synthetic resin reinforced by the high strength fibrous material and the bundled turns 7 of wire of the wound coil 5, of an intermediate insulating layer 9 having a relatively low thermal expansion coefficient, for example, approximate to the thermal expansion coefficient of the electric wire used to form the wound coil 5. According to a series of experiments conducted, it has been found that the intermediate layer 9 preferably has a thermal expansion coefficient of not more than 4×10^{-5} cm/cm/°C.

Material for the intermediate insulating layer 9 may be a synthetic resin admixed with a filler of inorganic material such as silica, alumina, hydrated alumina, calcium carbonate, magnesia, talc, clay, titanium oxide, mica, or glass. Such a mixture of synthetic resin admixed with inorganic filler is not suitable for use as an outermost covering for the bundled turns 7 of wire of the wound coil, but is quite adequate for use as an intermediate layer which may be relatively thin because the outermost insulating layer 8 acts as the primary insulation for the coil.

Because the intermediate layer 9 may be relatively thin, it is able to deform under the stresses set up therein, and because it has a low thermal expansion coefficient and it is less liable to formation of cracks than the outermost layer 8 then a highly reliable coil assembly can be manufactured according to the present invention.

As a method for forming the intermediate insulating layer 9, any known fluidized bed technique, such as an electrostatic fluidized bed technique, or a spray technique such as a electrostatic spray technique can be employed. In the practice of any of these known techniques, the resin admixed with the inorganic filler is applied in the form of a powder which facilitates the formation of a relatively thin intermediate insulating layer 9 of uniformly small thickness around the bundled turns 7 of wire of the wound coil 5. The synthetic resin material for the layer 9 may be epoxy resin, polyester resin or the like, and the manufacture of the coil assembly according to the present invention wherein the intermediate layer 9 is prepared from the synthetic resin containing the inorganic filler can be automatically carried out with no substantially complicated procedures involved.

Other possibilities for the synthetic resin material for the insulating layer 9 may include a rubber-like synthetic resin with metallic material as a filler.

In the embodiment shown in Fig. 8, a semi-conductive layer 10 is formed between the layer 9 and the outermost insulating layer 8 of fibre reinforced synthetic resin.

In the embodiment shown in Fig. 9, the semi-conductive layer 10 is composed of inner and outer semi-conductive plies 10a and 10b separated by a gap layer 11, as illustrated. Material for the inner and outer plies 10a and 10b and, therefore, the layer

10, may be made using any suitable material, such as carbon, a sheet containing carbon, a metallic compound or a metal, or synthetic resin containing such material. During the operation of the coil assembly of the construction shown in Fig. 9, since the potential of either of the inner and outer plies 10a and 10b is substantially equalized to that of the other of the inner and outer plies 10a and 10b, substantially no potential difference is created across the gap layer 11 and, therefore, no corona discharge occurs. Another advantage resulting from the provision of the gap layer 11 is that it can absorb variations in volume of either the inner or outer ply 10a, 10b which may result from variations in the ambient temperature, variations in the operating temperature of the coil assembly and/or variation in their dimensions due to aging. This means that the internal stresses in the assembly may be relieved.

Still referring to Fig. 9, the inner and outer plies 10a and 10b of the semi-conductive layer 10 are preferably firmly bonded to the intermediate layer 9 and the outermost insulating layer 8, respectively. This can be achieved by first of all applying a synthetic resin, such as a semi-conductive powdery synthetic resin, to the outer peripheral surface of the layer 9, to constitute the inner ply 10a then covering this with a material constituting a release agent, such as silicone resin or tetrafluoroethylene. The layer of release agent is then itself covered by a second semi-conductive material layer, for example, a carbon sheet, to constitute the outer ply 10b the whole being then covered by the fibre-reinforced synthetic resin layer 8. The assembly is then dipped in a solution of the synthetic resin and finally hardened. The release agent material prevents adhesion between the inner and outer ply material, and during the hardening stage, the release agent contracts to leave the gap layer 11. The gap layer 11 does not necessarily need to have a uniform thickness between the inner and outer plies 10a and 10b and in practice, this gap layer 11 allows the inner and outer plies 10a and 10b of the semi-conductive layer 10 to contact each other at various locations around the assembly and, accordingly, during the operation of the coil assembly, the plies 10a and 10b are charged with substantially equal potential.

According to another embodiment of the invention, if the wire forming the bundled turns 7 of the wound coil 5 is highly insulated or if the induced voltage between one layer and another of the coil assembly is sufficiently low, an additional semi-conductive layer 12 may be located between the bundled turns 7 of wire of the wound coil 5 and the layer 9 as shown in Fig. 10. The semi-conductive layer 10 is, as before, located between the layers 8 and 9.

The insulated wire forming the electromagnetic coil assembly of any of the constructions shown in Figs. 3 to 10 is preferably employed in the form of a self-fusible wire, that is, a wire sheathed with a thermoplastics material. If this type of wire is employed and subsequently coiled to form the bundled turns 7, the bundled turns 7 can easily by obtained with one turn firmly bonding to adjacent turns upon application of heat thereto. Therefore, any auxiliary elements, such as a temporarily binding tape, is not required to retain the shape of the bundled turns 7 of wire of the wound coil 5 prior to the application of the various layers 8 to 12 thereto.

WHAT WE CLAIM IS:—

1. A synthetic resin encapsulated coil assembly which comprises a wound coil consisting of a plurality of turns of insulated wire bundled together, a covering of synthetic resin containing a high strength fibrous material, said covering surrounding the bundled turns of insulated wire of the wound coil, an intermediate insulating layer positioned between the coil and the covering, and a semi-conductive layer positioned between the intermediate insulating layer and the covering.

2. A coil assembly as claimed in claim 1, wherein said intermediate insulating layer is formed by the application of a powdery resinous material onto the surface of said wound coil before the resin of the coil assembly is hardened.

3. A coil assembly as claimed in claim 1 or claim 2, wherein said intermediate insulating layer is a resinous layer containing an inorganic material.

4. A coil assembly as claimed in any one of the preceding claims, wherein said semi-conductive layer comprises two plies having a gap layer therebetween, one of said two plies being integrally connected to the intermediate insulating layer and the other of said two plies being integrally connected to the covering.

5. A coil assembly as claimed in claim 4, wherein said gap layer is formed by the application of a layer of release agent between the two plies of the semi-conductive layer before the resin of the coil assembly is hardened.

6. A coil assembly as claimed in any of

claims 1 to 5, in which the fibrous material comprises glass fibres.

7. A synthetic resin encapsulated coil assembly substantially as described hereinbefore with reference to and as illustrated in any of Figures 8 to 10 of the accompanying drawings.

MATSUSHITA ELECTRIC INDUSTRIAL CO. LTD.
Per: Boult, Wade & Tennant,
34 Cursitor Street,
London EC4A 1PQ.
Chartered Patent Agents.

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1978
Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

FIG. 1.

PRIOR ART

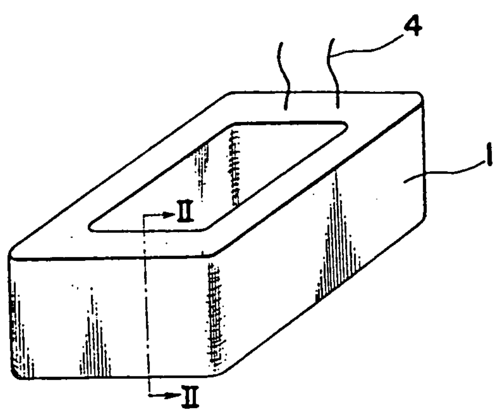


FIG. 2.

PRIOR ART

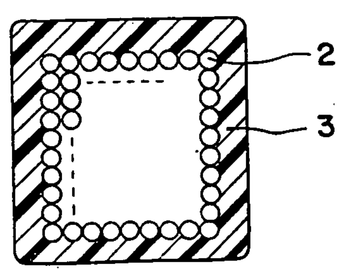


FIG. 3.

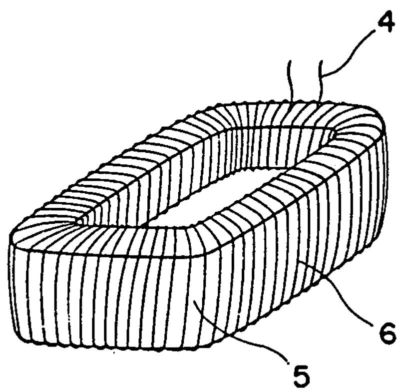


FIG. 4.

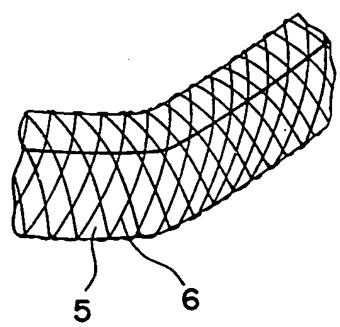


FIG. 5.

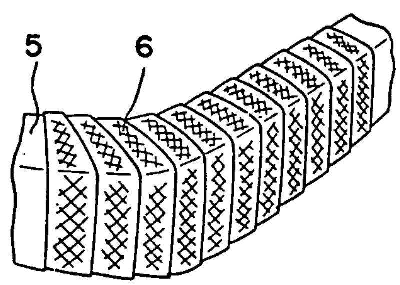


FIG. 6.

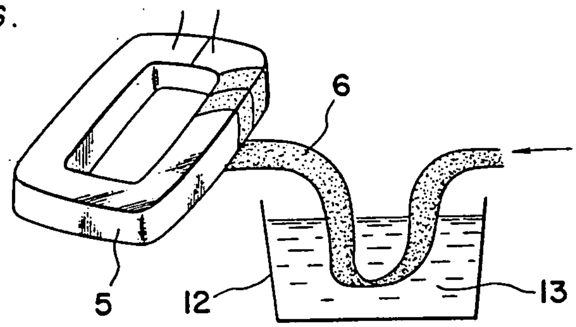
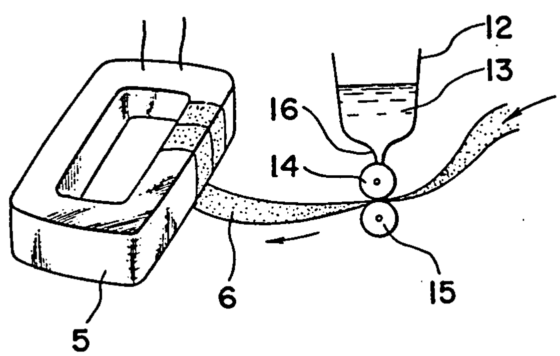


FIG. 7.



1525745 COMPLETE SPECIFICATION

4 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 4

FIG. 8.

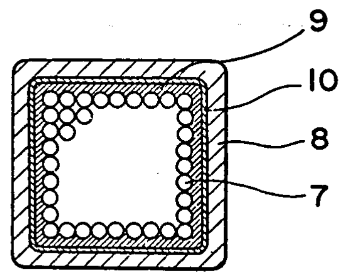


FIG. 9.

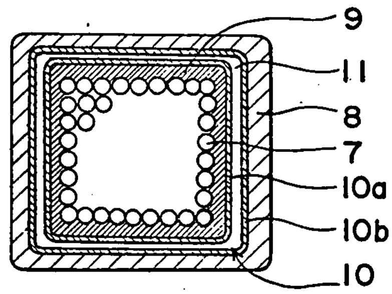


FIG. 10.